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Research Article

Effect of Braces on Framed Machine Foundation for Turbo Generator

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Abstract

Turbo generators are used for generation of electricity in large power plant which normally rest on frame foundation. These foundations are subjected to dynamic loading that result in higher section of beam and column. In the present work an attempt is made to optimize sizes of column & beam by incorporating different bracing systems. The analysis is carried out by 'Combined method' which computes the value of governing parameters, frequency & amplitude for satisfactory performance. The study focuses on the investigation of effectiveness of various bracing system i.e. 'V' bracing, 'A' bracing & 'Knee' bracing. The study reveals that, frequency is not a significant governing parameter as for all the cases of bracing system, frequency is observed to be within the permissible limit. However, variation in the amplitude for different type of bracings is significant. Therefore, bracing type is one of the important considerations in foundation design for controlling amplitude. This study reveals that frame foundation with 'V' bracing shows improved performance over bare frame; 'A' bracing shows improved performance than 'V' bracing and 'Knee' bracing shows best performance amongst all bracing types. Overall, in the given structural configuration, amplitude produced by 'Knee' bracing is almost 42 % lower than bare frame which significantly advocates the effectiveness of 'Knee' bracing. Therefore, even for reduced geometry of structural members, 'Knee' bracings are found still effective & workable resulting into overall economy.

Keywords*: Amplitude, Frequency, Foundation, Combined method, Rotary Machine, Frame foundation, Bracings*

1. Introduction

Machine foundations form an important part of any industrial building. With the rapid pace of industrial growth of the country a large number of machine foundations thus deserve a great importance in the context of our national economy and growth. Turbo-generators are used in various power plants for power generation. The turbo-generator foundation consists of turbine, generator and its auxiliaries mounted on a RCC frame structure as shown in Fig.1.

Jayarajan focuses on complexity of dynamic analysis to calculate natural frequency of vibration under a dynamic condition. He further found that natural frequency of foundation shall not fall within ±20% of operating frequency to avoid resonance. He also highlighted the dynamic analysis issues related to mathematical modeling of structure, soil and machine.

Mr.Irfan Shaikh studied different types of bracings for various capacity of turbo generator with constant speed. He tried different bracing pattern like Simple frame, frame with tie bracing & frame with cross bracing to optimize the size of beam & column. It is concluded that among all the bracing types, cross bracing frame is more effective.

In the present work a frame foundation for 10MW turbo generator with 6000rpm capacity is analyzed with different types of bracing. The parameters such as Horizontal, Vertical frequency, Horizontal & Vertical amplitude are studied using combined method. Study has been carried out to arrive at the optimum size of beam & column by providing different types of bracing. Three different cases of bracing systems i.e. *'V'* bracing, *'A'* bracing & *'Knee'* bracing for a 10MW turbo generator have been analyzed and compared. The objective of the work is to study the effectiveness of different type of bracing systems to safeguard against the occurrence of resonance conditions and to ensure that the amplitude of vibrations is restricted within the permissible limit.

2. Rotary machine

The turbo-generator foundation is a vital and expensive part in power plant. It is therefore, essential that the foundation is designed adequately for all possible combinations of static and dynamic loads.

The conventional framed foundation consists of (Fig.1) a heavy foundation slab called sole plate which is supported from underneath by soil or piles and which supports on its top a series of columns. The columns are connected at their top ends by

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longitudinal and transverse beams forming a rigid table called upper plate or table plate on which turbine portion rests.

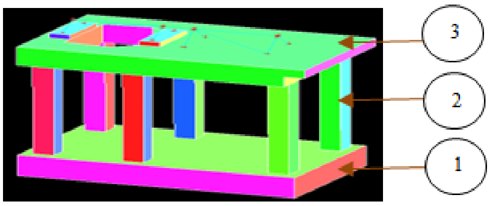


Fig.1 Typical Framed foundation Lower Slab, (2) Column, (3) Upper Slab,

3. Design data (IS 2974-Part III)

Required data for machine foundation is given as below.

3.1Machine Data

i) The data required include a detail-loading diagram showing the magnitude and position of all loads (static and rotating loads separately) acting on the foundation. The loading diagram should contain not only the loads but also the area over which the loads will be distributed on the foundation.

ii) The rated capacity of the machine.
iii) Operating Speed of machine.
iv) The layout of auxiliary equipment
v) The distribution of pipelines and platforms at their outer surfaces.

3.2 Principle design criteria

From view point of vibration, the natural frequencies of foundation system should be far away from the operating speed of machine as the critical speeds of the rotor, a clear separating margin of at least 20 percent should be ensured in design.

The amplitudes of vibration should be within the permissible limits. The permissible limits specified at the bearing level of the machine are stated as under:

a. For machine with operating speed ≥ 3000 rpm :
   Max. permissible Vertical amplitude - 0.02mm
   Max. permissible Horizontal amplitude - 0.04mm
b. For machine with operating speeds < 3000rpm:
   Max. permissible Vertical amplitude - 0.04mm
   Max. permissible Horizontal amplitude - 0.07mm

3.3 Structural Modeling

Following are the guidelines for the structural modeling of the foundation in accordance with IS: 2974 Part- III

a. Turbo-generator less than 100MW capacity with a regular framing arrangement, plane frame models may be adopted in the transverse and longitudinal direction.
b. Turbo-generator with capacity more than 100MW - space frame model is recommended.

In the present study, a plane frame model is used for analysis of turbo generator frame foundation.

4. Combined method' of dynamic analysis

For the dynamic analysis of framed foundations, three methods are available, namely, Resonance method, Amplitude method & combined method.

The basic objection to the resonance method is that it does not predict the extent of damage to the foundation; this has led to the adoption of the amplitude method developed by D.D.Barkan. According to this method, the fundamental requirement is that the amplitude of foundation under forced vibration should not exceed the permissible value. The resonance method and the amplitude methods are complimentary to each other.

This gave rise to the third method, known as Combined method. According to this method, while the possibility for resonance is investigated, the amplitude is also to be determined. In the case of under-tuned foundations, the maximum dynamic effects that occur during acceleration and deceleration stages are also considered in design.

All the methods mentioned above indicate that for purpose of dynamic analysis, each cross-frame of the foundation may be considered independently.
The following are the steps for combined method.

Steps

The equations to obtain the value of frequency & amplitude of machine foundation is as stated below

4.1 Frequency Calculation (f)

a) Vertical frequencies (f_n)v

The vertical frequency of the cross-frame is expressed as

$$(f_n)v = \frac{30}{\sqrt{\delta_v}} \text{ (Cpm)} \quad \text{(i)}$$

Where, δ_v is the total vertical deflection in meters at the mid-point of cross-beam.

$\delta_v = \delta_1 + \delta_2 + \delta_3 + \delta_4$
Where, $\delta_1, \delta_2, \delta_3$ and δ_4 are given by
Deflection due to concentrated load (P)

$$\delta_1 = \frac{Pl^3}{96EI_b} \frac{2K+I}{K+2} \quad \text{(ii)}$$

Deflection due to uniform distributed load (Q=ql)

$$\delta_2 = \frac{Ql^3}{384EI_b}\frac{5K+2}{K+2} \qquad \text{(iii)}$$

Deflection due to shear

$$\delta_3 = \frac{3l}{5EA_b}\left(P + \frac{Q}{l}\right) \qquad \text{(iv)}$$

Compression of column due to axial load (N) transferred from longitudinal girders

$$\delta_4 = \frac{h}{EA_c}\left(N + \frac{P+Q}{2}\right) \qquad \text{(v)}$$

The following notations are used

P = Concentrated load of machine
Q = Self weight per unit length of cross beam
N = Concentrated load on columns
A_b, A_c = Area of cross section of beam columns
I_b, I_c =Moment of inertia of beam, columns
E =Modulus of elasticity of foundation material
h =Effective height of column
l =Effective span of beam

$$K = \frac{I_b}{I_c} * \frac{h}{l} \qquad \text{(vi)}$$

Fig. 2a,2b_shows the loads, *P*, *Q&N* acting on a typical cross-frame.

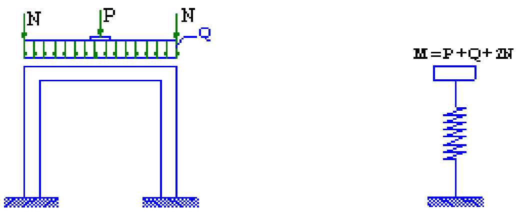


Fig.2a Loading diagram **Fig.2b** Mathematical model

Fig. Model system for a cross frame

b) Horizontal frequencies (f_n)h

The horizontal natural frequencies are obtained from the expiration

$$(f_n)h = 30\sqrt{\alpha_0 + \sqrt{\alpha_0^2 - \frac{\sum K_{hi}}{\sum W_i} * \frac{I_H}{I_G}}} \qquad \text{(vii)}$$

And

$$(f_n)h = 30\sqrt{\alpha_0 - \sqrt{\alpha_0^2 - \frac{\sum K_{hi}}{\sum W_i} * \frac{I_H}{I_G}}} \qquad \text{(viii)}$$

4.2 Amplitudes Calculation (a)

a)Vertical amplitudes (a_v)

$a_v = \mu\delta_v$ (ix)

b) Horizontal amplitudes (a_h)

a) Case–I [Simple Frame. (Without bracing)]

$a_h = \mu\delta_h$ (x)

Where

δ_V =Vertical displacement.

δ_h = Horizontal displacement

μ = Dynamic factor.

5. Problem Statement

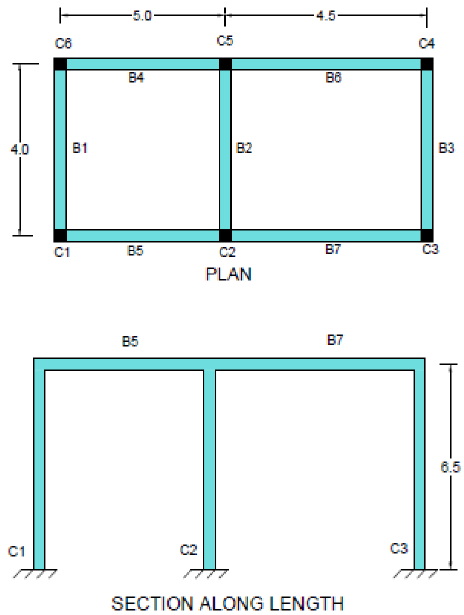
In the present work the detail study of 10MW Turbo generator with operating speed 6000rpm is discussed. Machine manufacturer specified the Minimum size of beam and column as given below.

Beam (B1 to B7) -1100mm x 1200mm,
Column (C1 to C6)-1200mm x 1200mm.
The details are as shown in Fig.4

For this framed type machine foundation four cases are considered as below.

a) Case I- Simple Frame.(Without bracing)
b) Case II-Frame with *'V'* bracing(300 x 400mm)
c) Case III- Frame with *'A'* bracing(300 x 400mm)
d) Case IV- Frame with *'Knee'* bracing(300 x 400mm)

The analysis is carried out for all the cases mentioned above. The performance criteria are Horizontal, Vertical frequency, Horizontal & Vertical amplitude. For all the cases these parameter are compared with permissible values (mentioned in 3.2). Various Trials are taken by reducing the sizes of beam & column. The results are shown in Table No.2, 3, 4 & 5respectively.



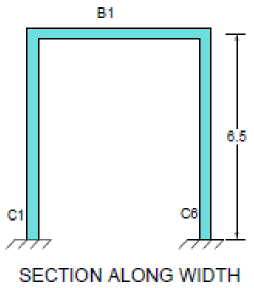


Fig.4 Case-I Simple frame (without bracing)

The Loading details as per manufacturer are shown in Table No.1

Table No.1: Loading Data

Sr.No	Machine Weight		Rotating Weight	
	Frame	**Load**	**Beam**	**Column**
1	A	70kN	8kN	10 kN
2	B	110 kN	14kN	14 kN
3	C	90 kN	20	20 kN

For the Simple frame the six trials are considered as mentioned in Table no.2. The sizes of beam & column for trial 1 are provided by machine manufacturer & for remaining other trials from trial 2 to trial 6 are considered for the present study by reducing the sizes of beam, column as shown in the Table No. 2.

Table No.2 Case–I [Simple Frame (Without bracing)]

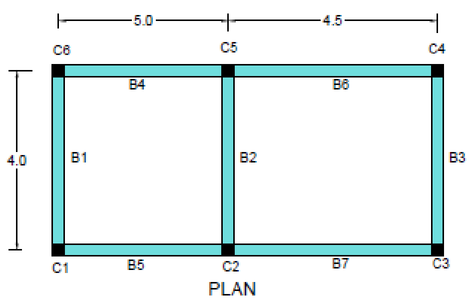
Trials	Beam. (mm)	Column. (mm)	Frequency		% age reduction in frequency		Amplitude		Max. B.M		Max.S.F		Remark
			Hor. (cps)	Vert. (cps)	Hor. (%)	Vert. (%)	Hor. (mm)	Vert. (mm)	Column (kNm)	Beam. (kNm)	Column (kN)	Beam. (kN)	
1	1100x1200	1200x1200	32.26	75.08	-	-	0.0289	0.0109	6.358	38.544	9.306	145.865	safe
2	1000x1100	1000x1000	30.68	73.10	4.90	2.64	0.0331	0.0152	6.216	38.429	9.201	145.787	safe
3	800x1000	800x800	28.27	70.91	12.37	5.55	0.0375	**0.0205**	6.094	38.328	9.184	145.642	Un safe
4	700x900	900x900	24.54	69.05	23.93	8.03	**0.0416**	**0.0241**	5.908	38.289	9.089	145.518	Un safe
5	600x800	700x700	23.16	67.01	28.21	10.75	**0.0458**	**0.0286**	5.827	38.164	9.925	145.412	Un safe
6	500X550	600x000	22.21	66.23	31.15	11.79	**0.0477**	**0.0317**	5.787	38.025	9.925	145.325	Un safe

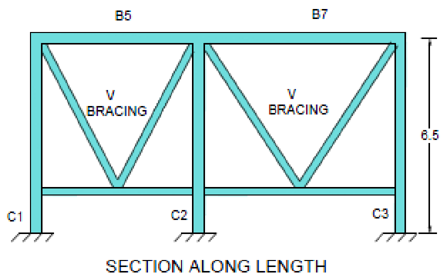
Table No.3 Case–II ['V' bracing.(300mm x 400mm]

Trials	Beam. (mm)	Column. (mm)	Frequency		% age reduction in frequency		Amplitude		Max. B.M		Max.S.F		Remark
			Hor. (cps)	Vert. (cps)	Hor. (%)	Vert. (%)	Hor. (mm)	Vert. (mm)	Column (kNm)	Beam. (kNm)	Column (kN)	Beam. (kN)	
1	1100x1200	1200x1200	33.56	76.42	-	-	0.0269	0.0100	6.825	39.324	9.92	146.665	safe
2	1000x1100	1000x1000	32.02	74.05	4.59	3.10	0.0311	0.0143	6.721	39.292	9.801	146.527	safe
3	800x1000	800x800	30.15	73.11	10.16	4.33	0.0352	0.0191	6.624	39.112	9.764	146.442	safe
4	700x900	600x600	29.14	72.12	13.17	5.63	**0.0400**	**0.0230**	5.728	39.098	9.608	146.332	Un safe
5	600x800	500x500	27.05	69.12	19.40	9.55	**0.0437**	**0.0270**	5.637	38.986	9.525	146.212	Un safe
6	600X700	500x500	26.15	68.02	22.08	10.99	**0.0452**	**0.0297**	5.587	38.825	9.415	146.185	Un safe

It is observed from Table No.2 that for bare frame the minimum required size of the beam is 1000 x 1100mm & minimum required size of column is 1000 x 1000mm.For further reduction in the sizes the amplitude developed is found to be more than permissible values (maximum permissible amplitude in horizontal direction is 0.04mm & maximum permissible amplitude in vertical direction is 0.02mm).

b) CASE–II ['V' bracing.(300mm x 400mm]





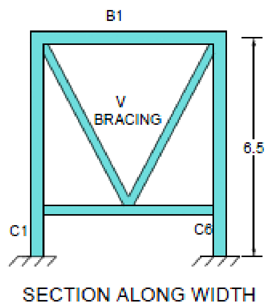
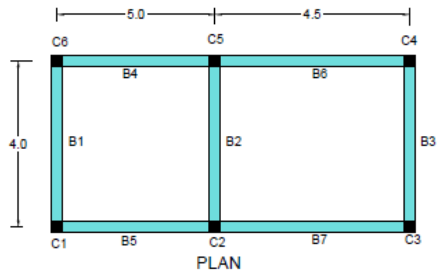


Fig.5 Case-II 'V' bracing

For the frame with *'V'* bracing.(300mm x 400mm) six trials are considered, the sizes beam & column for trial 1 are provided by machine manufacturer & remaining trials from trial 2 to trial 6 are considered for the present study by reducing the sizes of beam, column as mentioned in the Table No. 3.

It is observed from Table No.3 that for frame with *'V'* bracing the minimum required size of the beam is 800 x 1000mm & minimum required size of column is 800 x 800mm.For further reduction in the sizes the amplitude developed is found to be more than permissible values (maximum permissible amplitude in horizontal direction is 0.04mm & maximum permissible amplitude in vertical direction is 0.02mm).

c) Case–III ['A' bracing.(300mm x 400mm]



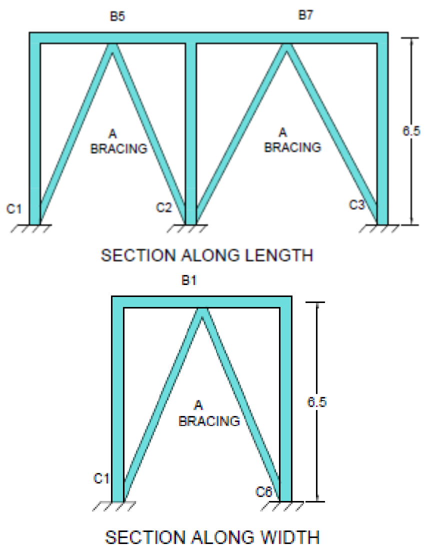


Fig.6 Case-III 'A' bracing

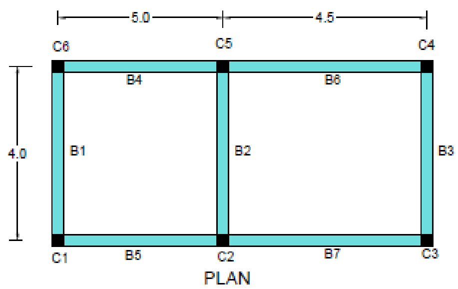
For the frame with *'A'* bracing.(300mm x 400mm) six trial are considered, the sizes beam & column for trial 1 are provided by machine manufacturer & remaining trials from trial 2 to trial 6 are considered for the present study by reducing the sizes of beam, column as mentioned in the Table No.4.

Table No.4 CASE–III ['A' bracing.(300mm x 400mm]

Trials	Beam. (mm)	Column. (mm)	Frequency		% age reduction in frequency		Amplitude		Max. B.M		Max.S.F		Remark
			Hor. (cps)	Vert. (cps)	Hor. (%)	Vert. (%)	Hor. (mm)	Vert. (mm)	Column (kNm)	Beam. (kNm)	Column (kN)	Beam. (kN)	
1	1100x1200	1200x1200	34.83	77.22	-	-	0.0216	0.0064	6.958	39.914	10.662	147.966	safe
2	1000x1100	1000x1000	33.06	75.10	5.08	2.75	0.0260	0.0117	6.826	39.829	10.541	147.862	safe
3	800x1000	800x800	31.23	74.09	10.33	4.05	0.0325	0.0156	6.794	39.712	10.462	147.775	safe
4	700x900	600x600	29.95	73.15	14.00	5.27	0.0382	0.0196	6.625	39.628	10.321	147.628	safe
5	600x800	500x500	28.12	72.01	19.27	6.75	**0.0418**	**0.0235**	6.542	38.516	10.222	147.521	Un safe
6	600X700	500x500	27.22	69.22	21.84	10.36	**0.0433**	**0.0277**	6.444	38.422	10.128	147.405	Un safe

It is observed from Table No.4 that for frame with 'A' bracing the minimum required size of the beam is 700 x 900mm & minimum required size of column is 600 x 600mm.For further reduction in the sizes the amplitude developed is found to be more than permissible values (maximum permissible amplitude in horizontal direction is 0.04mm & maximum permissible amplitude in vertical direction is 0.02mm).

d) Case–IV ['Knee' bracing.(300mm x 400mm]



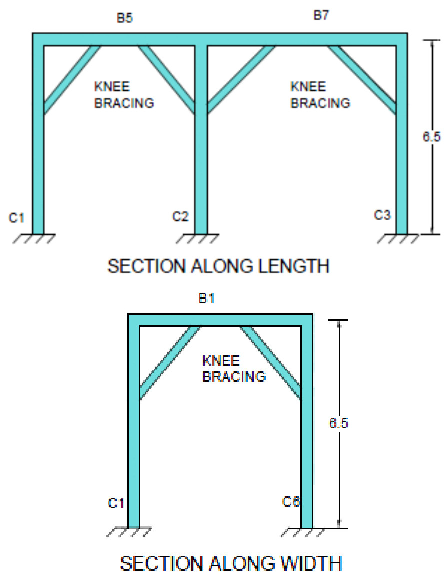


Fig.7 Case-III 'Knee' bracing

Table No.5 Case-IV 'Knee' bracing

Trials	Beam. (mm)	Column. (mm)	Frequency		% age reduction in frequency		Amplitude		Max. B.M		Max.S.F		Remark
			Hor. (cps)	Vert. (cps)	Hor. (%)	Vert (%)	Hor. (mm)	Vert. (mm)	Column (kNm)	Beam. (kNm)	Column (kN)	Beam. (kN)	
1	1100x1200	1200x1200	35.69	78.65	-	-	0.0166	0.0045	7.865	40.724	11.922	148.76	safe
2	1000x1100	1000x1000	33.89	76.10	5.03	3.24	0.0220	0.0092	7.742	40.644	11.842	148.659	safe
3	800x1000	800x800	32.27	74.91	9.57	4.76	0.0285	0.0121	7.635	40.563	11.754	148.526	Safe
4	700x900	600x600	31.54	73.92	11.62	6.01	0.0352	0.0154	7.525	40.422	11.682	148.418	Safe
5	600x800	500x500	29.56	72.50	17.16	7.82	0.0388	0.0191	7.465	40.336	11.523	148.373	Safe
6	600X700	500x500	27.54	70.23	22.82	10.71	**0.0416**	**0.0232**	7.315	40.254	11.432	148.212	Un safe

Table No.6 Evaluated minimum Sizes of beam and column for different cases

Case	Size of beam(mm)	Size of column(mm)
Manufacturer size	1100x1200	1200x1200
Simple Frame(Bare Frame)	1000 x 1100	1000 x 1000
Frame with *'V'* bracing	800 x 1000	800 x 800
Frame with *'A* bracing	700 x 900	600 x 600
Frame with *'Knee'* bracing	600 x 800	500 x 500

For the frame with 'Knee' bracing.(300mm x 400mm) six trial are considered, the sizes beam & column for trial 1 are provided by machine manufacturer & remaining trials from trial 2 to trial 6 are considered for the present study by reducing the sizes of beam, column as mentioned in the Table No.5.

It is observed from Table No.5 that for frame with 'Knee' bracing the minimum required size of the beam is 500 x 500mm & minimum required size of column is 600 x 700mm.For further reduction in the sizes the amplitude developed is found to be more than permissible values (maximum permissible amplitude in horizontal direction is 0.04mm & maximum permissible amplitude in vertical direction is 0.02mm).

The safe minimum required sizes of beam & column against manufacturer sizes are as shown in Table No.6. This reveals that the 'Knee' bracing produces satisfactory performance even lower sizes of beams and columns. Thus, reduction in the sizes of members leads to overall economy.

6. Parametric Investigation

For 10 MW Turbo generator & 6000rpm operating speed of machine the framed type machine foundation is studied for various cases. For each case, size optimization of beam & column is done. For the optimization, frequency & amplitude are compared with permissible limit (mentioned in 3.2). The overall comparison is presented for following parameters.

1) Frequency:- 1) Horizontal frequency, 2) Vertical frequency
2) Amplitude:- 1) Horizontal amplitude, 2) Vertical amplitude

6.1 Frequency

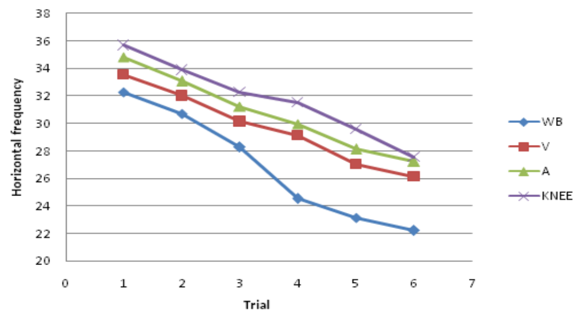
It is well known fact that, to safeguard against the occurrence of resonance, the natural frequency of foundation shall be ± 20percent away from the operating frequency. In the present study the natural frequency for various alternate combination of bracing is evaluated and compared with the operating frequency to ensure non occurrence of resonance. Two frequencies are studied, namely, Horizontal frequency and Vertical frequency. The results are presented in Graph1& 2.

6.1.1 Horizontal frequency

It is observed from Graph1 that in case of bare frame the horizontal frequency goes on reducing from trial 1 to trial 6 due to reduction in the size of beam and column. The same trend is observed for foundation with various bracing system/s.

However, the frequency increases by 4 percent in case of *'V'* bracing with respect to *'Bare'* frame; further increase in case of *'A'* bracing by 3.8 percent with respect to *'V'* bracing and further increase in case of *'Knee'* bracing by 2.5 percent with respect to *'A'* bracing almost upto trial 3.

From trial 4 to trial 6 frequency increase in case of *'V'* bracing by 18.74 percent with respect to bare frame; in case of *'V'* bracing; further increase in case 'A' bracing by 2.77 percent with respect to *'V'* bracing and further increase in case of *'Knee'* bracing by 5.3 percent with respect to *'A'* bracing.



Graph1-Horizontal frequencies for various cases (10MW capacity, 6000rpm)

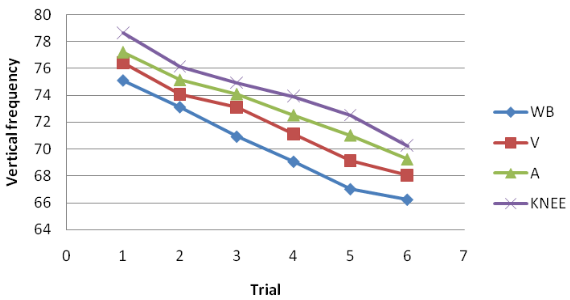
It is further observed that all cases satisfies Principle design criteria of horizontal frequency of frame foundation i.e horizontal frequency is less than 0.8 times frequency of machine(0.8 x 100=80cps).Therefore, study reveals that horizontal frequency is not governing the design as for all the cases the frequency is well below 20 percent of operating frequency

6.1.2 Vertical frequency

It is observed from Graph2 that in case of bare frame the vertical frequency goes on reducing from trial 1 to trial 6 due to reduction in the size of beam and column. The same trend is observed for foundation with all bracing system.

However the frequency increases by 1.78 percent in case of *'V'* bracing with respect to *'Bare'* frame; further increase in case *'A'* bracing by 1.04 percent with respect to *'V'* bracing and at last further increase in case of *'Knee'* bracing by 1.85 percent with respect to *'A'* bracing almost upto trial 2.

From trial 3 to trial 6 frequency increase in case of 'V' bracing by 3.1percent with respect to *'Bare'* frame; in case of *'V'* bracing; ; further increase in case *'A'* bracing by 1.34 percent with respect to *'V'* bracing and at last further increase in case of *'Knee'* bracing by 1.1 percent with respect to *'A'* bracing.



Graph2-Vertical frequencies for various cases (10MW capacity, 6000rpm)

It is observed that all cases satisfy Principle design criteria of vertical frequency of frame foundation i.e vertical frequency is less than 0.8 times frequency of machine (0.8 x 100=80cps).Therefore study reveals that vertical frequency is not governing the design as for all the cases the frequency well below 20 percent of operating frequency.

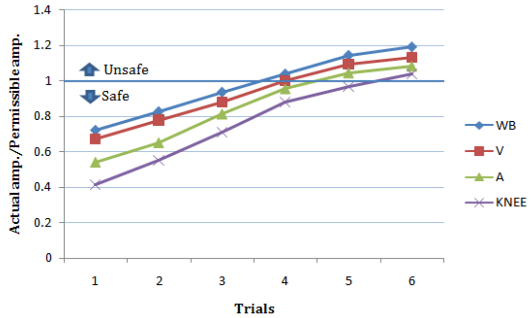
The Study reveals that, frequency is not a significant & governing parameter as for all the cases of bracing system, frequency is observed to be within the permissible limit. However, among all the cases of bracing, *'Knee'* bracing is most effective as it produces least vertical & horizontal frequency & therefore, gives better performance for even lower sizes of beams and columns.

6.2 Amplitude

The permissible amplitude for different machine is usually provided by machine manufacturer for their satisfactory performance. However in accordance with P. Shrinivasulu, the permissible Horizontal amplitude & Vertical amplitude for rotary machine(operating speed more than 3000rpm) are 0.04mm and 0.02mm respectively. In the present study Horizontal amplitude and Vertical amplitude for various bracing systems are studied and presented in Graph3 and 4.

6.2.1 Horizontal amplitude

It is observed from Graph3 that for bare frame the Horizontal amplitude goes on increasing with increase in number of trials leading to increase in ratio of actual amplitude to permissible amplitude. The same trend is observed for all type of bracing system.



Graph3-Horizontal amplitude for various cases (10MW capacity, 6000rpm)

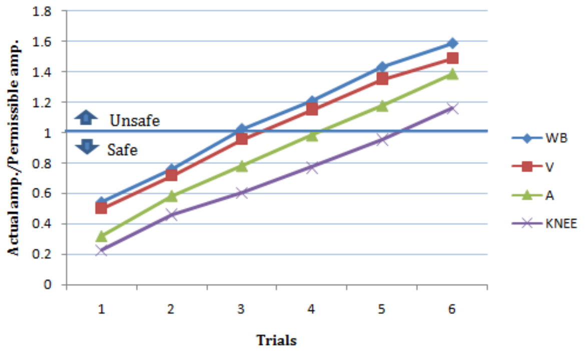
It is observed from the Graph3 that, amplitude ratio decrease by 6.92percent in case of *'V'* bracing with respect to *'Bare'* frame; further *'A'* bracing reduces the amplitude ratio by 19.7percent with respect to *'V'* bracing and further *'Knee'* bracing reduces the amplitude ratio by 23.14 percent with respect to *'A'* bracing. This shows the improvements in the performance of structure from *'Bare'* frame to *'Knee'* bracing.

However it is observed that up to trial 3, all bracing systems produces safe amplitude. Beyond trial 3, the effectiveness of *'Bare'* frame, *'V'* bracing; 'A' bracing and *'Knee'* bracing is observed to be unsafe as it produces unsafe amplitude. The *'Knee'* bracing is observed to be safe for minimum possible size corresponding to trial 5.Therefoere, among all these bracing systems *'Knee'* bracing system observed to be more effective.

6.2.2 Vertical amplitude

It is observed from Graph4 that for bare frame the Vertical amplitude goes on increasing with increase in number of trials leading to increase in ratio of actual amplitude to permissible amplitude. The same trend is observed for all type of bracing system.

It is observed from the Graph 4 that, amplitude ratio decrease by 8.25percent in case of *'V'* bracing with respect to *'Bare'* frame; further *'A'* bracing reduces the amplitude ratio by 36percent with respect to *'V'* bracing and further *'Knee'* bracing reduces the amplitude ratio by 29.68 percent with respect to *'A'* bracing. This shows the gradual improvements in the performance of structure from bare frame to 'Knee' bracing



Graph4-Vertical amplitude for various cases (10MW capacity, 6000rpm)

It is observed that up to trial 2 all bracing systems produce safe amplitude. Beyond trial 2, 'Bare' frame, *'V'* bracing*; 'A'* bracing *and 'Knee' bracing* are observed to be unsafe as these produces amplitude which are higher than permissible one. The *'Knee'* bracing is observed to be safe for even lower size up to trial 5.Therefoere among all these bracing system *'Knee'* bracing system observed to be more effective.

Overall it is observed that amplitude significantly decreases due to incorporation of bracings. The amplitude controls the effectiveness of bracing systems. The study reveals that among all the bracing systems and *'Bare'* frame, *'Knee'* bracing is observed to be more effective as it produces satisfactory performance for even lower sizes of beam and column

Conclusion

In this present study analysis of framed machine foundation is performed for different framing arrangements. Parametric Investigation is carried out using different types of bracing patterns. The maximum vertical and horizontal amplitudes, maximum vertical and horizontal frequencies are compared for different bracing arrangement. The summarized conclusions are presented below.

1. It is observed that in all cases, all the trials satisfy the governing criteria of a frequency, i.e natural frequency of foundation is less than 20percent of operating frequency of a machine from the resonance perspective.
2. It is observed from the study that the amplitude controls the performance of structure and is the governing parameter to evaluate the effectiveness of bracing system. Amongst all the cases of bracing the *'Knee'* bracing is observed to be workable & effective as it satisfies the Horizontal frequency, Vertical frequency, Horizontal amplitude & Vertical amplitude requirement, even for lower size of beam & column.
3. The study reveals that reduction in the size of frame, satisfying codal provision (IS 2974-PartIII) is possible to obtain by iterative process, instead of using the sizes provided by manufacturer. The optimization study will lead to determine the minimum required sizes for satisfactory performance of structure which ultimately will lead to achieve overall economy with more efficient bracing system.

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